Recreational Flows

for paddling along rivers in southern Alberta

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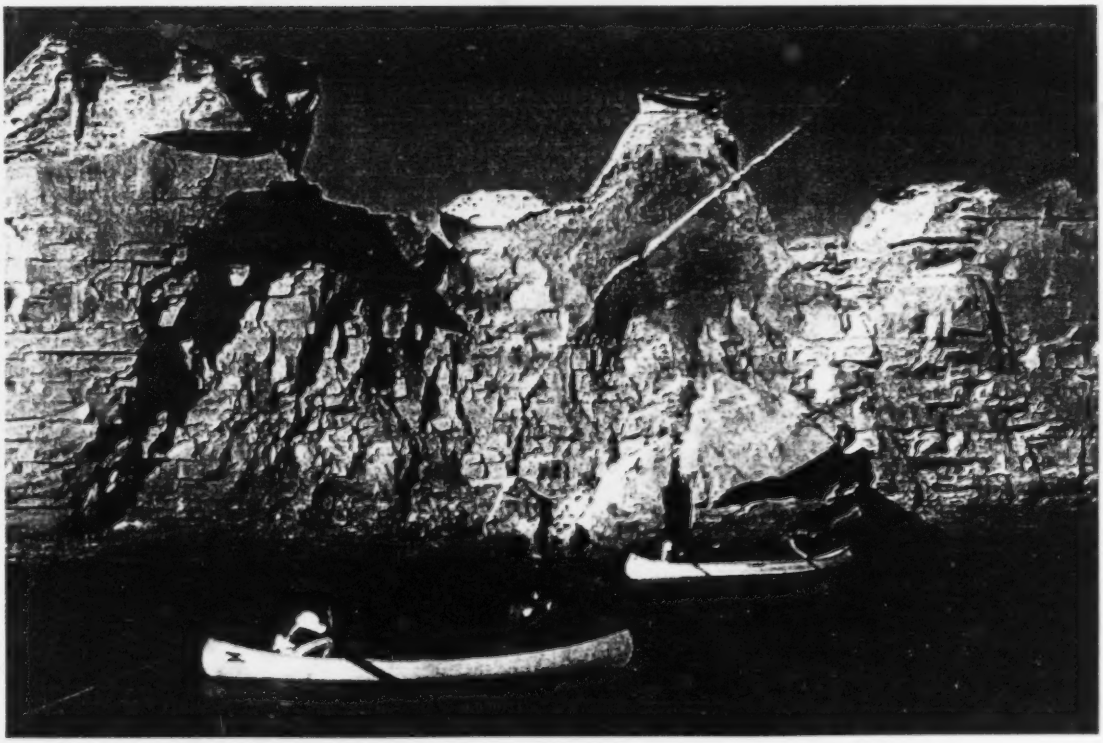

Sufficient flow along the Milk River near Verdigris Coulee.

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Executive Summary

This report develops and applies methods to determine recreational flows (RF) for regulated (dammed) and free-flowing (non-dammed) streams of the Oldman River Basin and the Milk and South Saskatchewan rivers in southern Alberta. Specific RF values were determined for minimal flows, low flows that still provide a worthwhile paddling opportunity, and preferred or sufficient flows that represent the low end of the favored flow range.

The principal analysis compared four approaches for determining RF. River Trip Report Cards provided a mail-in *paddler survey* conducted by Alberta Environment. *Expert opinion* recommendations were obtained from three regional paddling guides that were considered to be comprehensive and credible. A *multiple-flow comparison* was conducted by the authors with differing groups, boats and flows. An objective *hydrometric analysis*, the depth, discharge method, applied stage/discharge functions to determine flows that would satisfy depth criteria of 60 and 75 cm (2 and 2.5 ft).

The different methods produced highly consistent results (73% overall agreement), indicating that all methods are appropriate and valid. Further, the minimal RF values were close to the mean annual discharges for the small and medium-sized river reaches (88% agreement).

Following the integration of these analyses, the following values were determined for the southern Alberta streams (from north to south and west to east):

River Reach	Minimal Flow m^3/s *	Preferred Flow
Upper Oldman	16	25
Lower Oldman	30	55
Willow Creek	6	10
Crowsnest	7	13
Castle	17	25
Upper Waterton	16	30
Lower Waterton	21	40
Belly	10	15
Upper St. Mary	17	30
Lower St. Mary	19	35
Milk	13	20
South Saskatchewan	60	100

*cubic meters per second ('cms')

A comparison of methods for evaluating instream flows
for recreational paddling along rivers in southern Alberta, Canada

ABSTRACT: Four methods were compared for determining recreational flows (RF) for paddling canoes, kayaks and rafts on ten river reaches in the Oldman River Basin of southern Alberta. Two flow criteria were evaluated: 'minimal flow', the low flow that still provides a reasonable quality river trip, and 'sufficient' or 'preferred flow', the lower end of the favored flow range. A voluntary, mail-in *paddler survey* from 1983 to 1997 produced 394 responses (4251 paddler days) relative to flow suitability. An *expert opinion* approach considered flow recommendations from three regional paddling guides that were considered to be comprehensive and credible. A *multiple-flow comparison* involved about 20 paddle trips per reach by the authors with differing groups, boats and flows. These subjective approaches were compared to an objective, *hydrometric analysis*, the *'depth, discharge method'* (DDM), that applied stage/discharge functions to determine flows that would satisfy depth criteria of 60 and 75 cm (2 and 2.5 ft). The four approaches produced very consistent results indicating that all methods were valid. The DDM minimum flows were closely correlated with the means of the subjective methods ($r^2 = 0.73$). Typical minimal and sufficient flows were about 15 and 30 m^3/s, respectively, for the medium-sized river reaches that had average annual discharges (mean Q) of about 20 m^3/s. A very close correlation ($r^2 = 0.88$) between the minimum flow and mean Q suggests that mean Q can provide an initial estimate for RF for rivers of this type and size. We recommend that future RF studies commence with the DDM since it is quick, inexpensive and objectively defensible. This would provide guidelines for subsequent subjective assessments to refine the RF analysis.

INTRODUCTION

In Alberta and across North American there have recently been major changes in the appreciation of environmental, aesthetic and recreational values provided by rivers (Gillilan and Brown 1997). The changes in public awareness and opinion in Alberta were particularly catalyzed by the controversy surrounding the Oldman River Dam that impounded reaches of the Oldman, Castle and Crowsnest rivers in southwestern Alberta in 1993 (Fig. 1).

Figure 1. Map of southern Alberta showing principal rivers including the Oldman River tributaries and other streams that were investigated in the present study are designated. Triangles indicate major dams. For the southern tributaries of the Oldman River, 'L.' and 'U." indicate Lower and Upper, respectively.

During the Oldman Dam controversy, it became clear that non-consumptive uses of Alberta's streams were poorly understood and that this hindered comprehensive river resource management. The concept of instream flow needs (IFN), flows that were required particularly for environmental aspects such as fisheries, water quality and riparian ecosystems, emerged as prominent concerns. Analyses of IFN were subsequently considered in the development of the operations plans for the Oldman Dam (Rood and Mahoney, 1998).

While environmental IFN analyses lead to the implementation of ramping flows for riparian vegetation (Rood and Mahoney, 2000), IFN for other non-consumptive uses were often neglected. By the early 1980's it was recognized that the consideration of recreational uses in flow scenario evaluation was hindered by the lack of understanding of recreational flows (RF). RF methodology has lagged behind environmental IFN analyses and in the early 1980's there were no broadly accepted methodologies. Consequently, as an initial investigation, Alberta Environment sought to gather input regarding flow sufficiency for recreation and established a voluntary, mail-in paddler survey program that commenced in 1983.

The survey continued through to 1997 with support from the paddling community as evidenced by steady contributions. However, there have been criticisms of the survey method and particularly questions regarding the defensibility of this subjective approach.

Consequently, the present study was conducted for two purposes. Firstly, it sought to assess, compare, and develop different subjective and objective methods for RF determination. Secondly, it attempted to apply these methods to define RF for the rivers of the Oldman River Basin and thus contribute information for the 'Year 2000 Review', a current comprehensive assessment of river resource management in southern Alberta.

MATERIALS AND METHODS

The study investigated all of the rivers of Alberta's Oldman River Basin and the adjacent Milk River (Fig. 1, Table 1). These rivers pass snowmelt and rainfall runoff from Rocky Mountain and foothills regions to the prairie regions that are extensively developed for crop production. There are three large dams in the Oldman Basin and additional weirs (low-head dams) and these are primarily managed to permit water storage and flow diversion to support agricultural irrigation.

The study compared four methods for RF determination:

(1) paddler survey,

(2) expert opinion,

(3) multiple flow comparison, and

(4) a hydrometric method based on depth criteria and stage-discharge analysis.

Table 1. Characteristics of river reaches of the Oldman River Basin and the Milk River, Alberta. The rivers are sequenced north to south and then west to east. Grade of difficulty is in accordance with the International Canoe Federation difficulty classification.

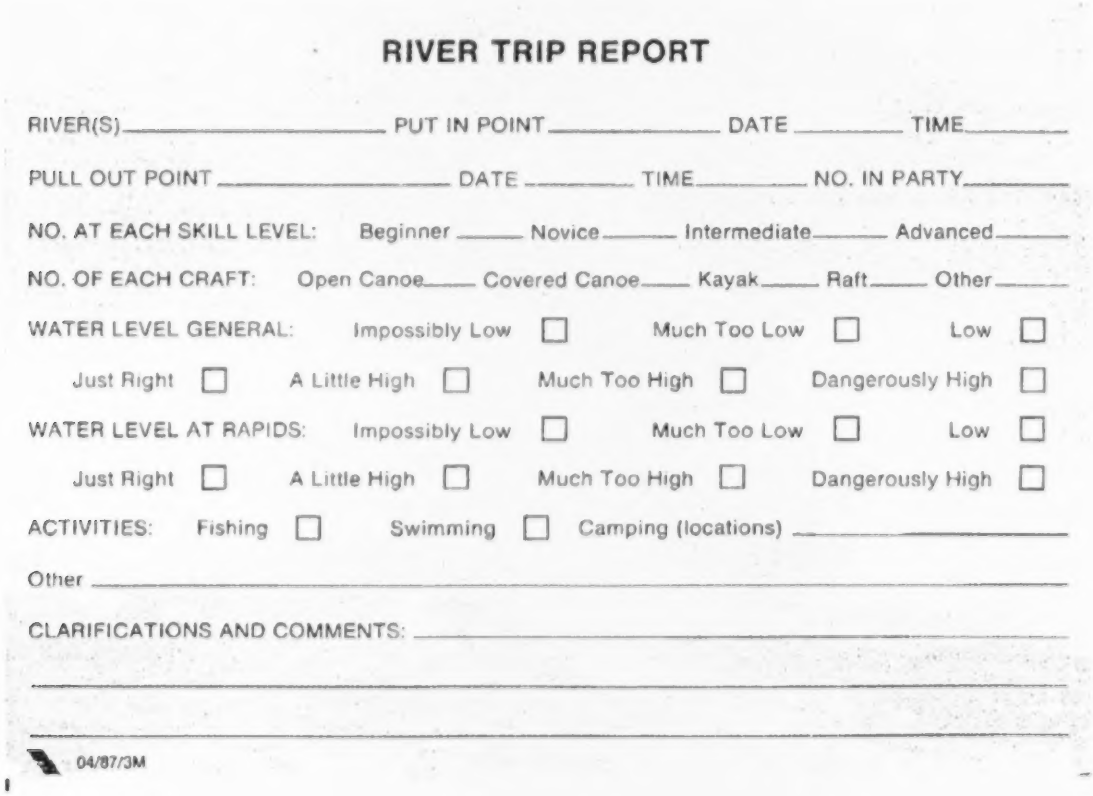
	Discharge (mean Q) m^3/s	Gradient m/km	Grade of difficulty	Hydrometric gauge name	River Trip Report Cards (RTRC) submitted. #cards	#boaters
Upper Oldman	13.1	5.75	II/III	Waldron	52	409
Middle Oldman	37.7	1.39	I+/II	Brocket	43	450
Lower Oldman	83.7	0.86	I	Lethbridge	43	295
Willow Creek	3.2	1.71	II	Lane Ck	5	32
Crowsnest	4.9	4.54	II	Frank	31	968
Carbondale			III/III+	Non-gauged	4	15
Castle	15.9	5.11	II/III	Beaver Mines	40	346
Upper Waterton	18.2	3.05	II/II+	Waterton Park	12	147
Lower Waterton	26.7	2.9	II	Glenwood		
Upper Belly	8.7	4.79	II	Mountain View	25	217
Upper St. Mary	20.7	3.4	II	International Border	37	361
Lower St. Mary	15.1	2.41	I+/III	Near Lethbridge	18	78
Milk	9.1	1.91	I	Milk River	84	933
total					394	4251

Paddler Survey

The River Trip Report Card (RTRC) provided the basis for a voluntary, mail-in survey. Post-card style surveys were developed in 1984 (Fig. 2) and distributed to paddling clubs in Alberta along with letters inviting participation. The cards were self-addressed with pre-paid mailing to encourage paddler response.

The cover letters stressed input regarding streams of the three sub-basins of the South Saskatchewan River Basin, the Oldman, Bow and Red Deer river basins. These provide the focus of irrigation in Alberta and in Canada and include some of Canada's most extensively regulated and diverted streams.

Figure 2. The River Trip Report Card (RTRC) used for the paddler survey in the present study. The opposite side included the return address along with postage payment authorization.



RIVER TRIP REPORT

RIVER(S)_____ PUT IN POINT_____ DATE _____ TIME_____

PULL OUT POINT _____ DATE _____ TIME_____ NO. IN PARTY_____

NO. AT EACH SKILL LEVEL: Beginner _____ Novice_____ Intermediate_____ Advanced_____

NO. OF EACH CRAFT: Open Canoe____ Covered Canoe____ Kayak____ Raft____ Other_____

WATER LEVEL GENERAL: Impossibly Low ☐ Much Too Low ☐ Low ☐

Just Right ☐ A Little High ☐ Much Too High ☐ Dangerously High ☐

WATER LEVEL AT RAPIDS: Impossibly Low ☐ Much Too Low ☐ Low ☐

Just Right ☐ A Little High ☐ Much Too High ☐ Dangerously High ☐

ACTIVITIES: Fishing ☐ Swimming ☐ Camping (locations) _____

Other _____

CLARIFICATIONS AND COMMENTS: _____

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Expert Opinion

To obtain expert opinion, guidebooks and maps for the regional streams were obtained and studied. Guides were selected that were the most comprehensive (included numerous rivers and reaches) and credible, providing accuracy regarding physical information such as accurate maps with correct locations and consistent ratings of major rapids and other major features. The flow assessments of these credible guides were utilized.

Multiple Flow Comparison

From 1982 to 2000, we systematically paddled all river reaches in the Oldman River Basin. We participated in group trips, particularly those of the Oldman River Canoe and Kayak Association (ORCKA). Records were kept of paddling trips with reference to sufficiency of flow. We paddled most reaches more than 20 times with trips in open canoes, kayaks and rafts. We joined diverse paddling groups ranging from expert paddlers at slalom race and river rendezvous events sponsored by the Alberta Whitewater Association to novice groups such as ORCKA beginner clinics.

Historical Hydrologic Data

Historical discharges (Q) were obtained for the river reaches from HYDAT, the hydrologic data base established for Water Survey of Canada gauging stations. Discharge (or 'flow') data involved daily mean flows and these were considered appropriate since no hydroelectric dams exist in the Oldman River Basin (although hydroelectric turbines are currently being installed at the Oldman Dam). Hydroelectric operations complicate RF analyses since they often invoke diurnal flow pulsing to respond to daily power demands.

The use of mean daily flows was problematic for the lower St. Mary river reach since the St. Mary Dam was historically operated in discrete steps due to insertion or removal of stop-logs in the spillway gates; this created abrupt flow changes within a day. For the multiple flow comparison, contacts were made with the operators of the St. Mary Dam to determine flow release schedules. The multiple flow comparison for the lower St. Mary reach benefited from advance notification of releases from the St. Mary Dam. Consequently, this method may be referred to as a 'controlled flow study', a type of multiple flow comparison involving deliberate flow adjustment (Whittaker et al. 1993, Shelby et al. 1998) that is becoming common with American Federal Energy Regulatory Commission (FERC) considerations for dam relicensing (Gangemi 2000).

Hydrometric Approach - Depth Discharge Method (DDM)

An objective, hydrometric approach was developed and is referred to as the depth criteria, stage-discharge method or more concisely as the depth discharge method (DDM). This method commences with the determinations of sufficient depths for various recreational activities. For paddling, depths of 50 cm or 60 cm (2 ft) were initially considered for determinations of minimum flows based on published reports (McGill 1982, Simmons et al. 1977) and typical paddle measurements, with the expectation that the depth should be sufficient to immerse a typical paddle blade. For possible sufficient flow determination, depths of 75, 90 (3 ft) and 100 cm were initially considered. The increased depth and flow would generally improve the appeal of many hydraulic features, reduce the chances of hitting rocks, permit the kayak Eskimo roll, and provide less obstructed conditions for a paddler who swims following a capsize. The comparisons of RF estimates from the subjective methods to the DDM estimates with different depths permitted the selection of the appropriate sufficient depth criterion.

Stage-discharge ratings tables were obtained for Water Survey of Canada gauging stations and the sites of those stations were visited to investigate the physical context of the gauging site. In particular, it was to be determined whether the channel form at the gauging site was typical of the reach or conversely, whether it was confined or otherwise impacted by an adjacent bridge or other artificial structures. Subsequently, stage-discharge ratings curves were plotted and discharges that would provide the depths considered were interpolated. Many river reaches included multiple gauging sites that enabled validation of the stage-discharge functions.

To investigate the magnitude of site-specific variation in stage-discharge function, ten sites were established along the upper St. Mary River that were considered to represent the range of geomorphic contexts: confined canyon versus open valley, gravel and cobble versus bedrock stream bed, and upstream of, at, and downstream of rapids. Iron rebar was positioned at the river's edge during a period of 'sufficient' flow (24 m^3/s) and the elevational change was measured with a transit and staff gauge as the river flow fell below the 'minimum' level (to 10 m^3/s).

RESULTS AND DISCUSSION

Paddler Survey - River Trip Report Card (RTRC)

An important aspect of a paddler survey method for RF determination is the format and text. Relative to the RTRC, it may have been preferable if the sequential ratings were positioned on a single line to simplify quantitative comparison. An alternate format could have included a tabular format with the descriptive categories listed at the top and two rows of open boxes for paddler responses for the overall river ratings and rapid ratings.

The inclusion of two ratings lines for 'river' and 'rapids' was useful since it provided respondents with two ratings opportunities. The different categories were intended to reflect the expectation that rapids represent river features where the water is typically swifter and shallower and the occurrence of boulders or bedrock outcrops would limit the navigable route. It was consequently expected that higher flows might be required at rapids than for pools.

This expectation was frequently supported as a number of RTRC reported overall flows as 'just right' whereas flows at rapids were 'low'. However, this was not a uniform pattern. For some reaches such as the Castle River, the bedrock-confined whitewater segment through Castle Canyon is paddleable at much lower flows than the broader, gravel- and cobble-bed segments upstream and particularly, downstream. In the canyon, the stream is confined to a single narrow channel and the bedrock ledges are typically sloped or notched to provide passable routes even at flows below 10 m^3/s. In contrast, the cobble and gravel riffles in the open and more-freely meandering reach downstream become much too low for boating at about 15 m^3/s.

A second and more general benefit from the provision of two response lines for 'river' and 'rapids' was that this provided respondents with an opportunity for intermediate assessments. For example, if a paddler group considered a flow as slightly low, they could provide 'just right' and 'low' for the two categories to reflect the intermediate assessment. This was also useful for the statistical analyses of the RTRC since the intermediate assessments provided additional ranking score categories for both regression analyses and analyses of variation.

With respect to the RTRC text, it might have been preferable to include equivalency across the low and high scales. Thus, both 'slightly low' and 'slightly high' could have been provided, in addition to 'low' and 'high'. A future scale sequence could include: much too low, low, slightly low, just right, slightly high, high, and much too high. This would produce a 7-point scale with equivalency of low and high categories and would omit the particularly ambiguous terms 'impossibly' and 'dangerously'. 'Impossibly' is

problematic since a canoe or kayak can be dragged over shallow riffles between pools even at very low flows. 'Dangerously' introduces an especially subjective judgment that is likely to vary considerably across paddlers, depending on their skill and comfort levels and numerous other factors.

Relative to the survey semantics, the terms undoubtedly raised different views across the paddlers; it would have been helpful to provide some guidance about assessment. As a point of reference, we consider that 'low' or 'high' would not represent 'ideal' flows but would still provide a reasonable quality paddling experience. Thus, a paddler group would consider such flows as worthy of return. Conversely, flows of 'much too low' or 'much too high' would hinder the paddling experience sufficiently that the group would not wish to return to a similar flow. We'd thus suggest that the rating would reflect the paddlers' likelihood of choosing a repeat experience. This is still somewhat equivocal since proximity will influence choice. A paddler living adjacent to a stream may choose to paddle it at unfavorable levels since there is minimal travel time commitment. Conversely, distant paddlers would be more selective relative to acceptable flows.

RTRC Responses

RTRC were submitted for rivers across Alberta but tended to focus, as desired, on the rivers of the South Saskatchewan River Basin and particularly for the rivers of the Oldman, Bow and Red Deer sub-basins. The Bow and Red Deer basins are situated closer to the major cities of Calgary and Edmonton and more RTRC were submitted for these than for the Oldman River Basin. However, the Oldman Basin contains the streams that are most heavily diverted for irrigation and consequently, this Basin provided the focus of this initial RF study.

A total of 395 RTRC were submitted for the Oldman Basin (for convenience the Milk River will be grouped with the Oldman Basin) and 394 were submitted for the 12 principal streams listed in Table 1 (one card was submitted for Lynx Creek). The numbers of responses varied from 4 for the Carbondale River, a challenging whitewater run with a limited paddling season to 84 for the Milk River. The Milk River is situated in a particularly distinctive landscape with abundant and dramatic sandstone 'hoodoos', mushroom-shaped rock features, and one of North America's largest concentrations of Native American petroglyphs (rock etchings). The Milk River has been featured in a number of articles in popular paddling magazines.

The RTRC represented an average of 11 boater days per card but it is likely that the level of consultation with the different trip members would have varied considerably across submissions. The Carbondale and Lower St. Mary groups were small, probably partly because these two reaches have unpredictable paddleable periods and consequently are seldom included in formal trip schedules of paddling clubs.

The largest groups represented by the RTRC were for the Crowsnest River that was commonly the site of an annual provincial whitewater slalom race and river rendezvous.

Across all RTRC, more than one-half indicated that the flows were 'just right'. This probably partially reflected the paddlers' enjoyment of the overall paddling experience that resulted from favorable social (Heywood 1987) and environmental conditions (Knopp et al. 1979) that promoted approval of flow conditions. Additionally, prospective paddlers will attempt to choose a river reach with suitable flow. Particularly after an automated 'flow phone' was implemented in the early-1990s, it was easy for remote paddlers to identify reaches with suitable flows. The provision of Internet-based flows in 1998 and the addition of near real-time flow data in 2000 should increase this trend. As a group, the paddling community is becoming more sophisticated about flow information and paddling clubs and outdoor equipment stores are increasingly tending to advertise flow information and provide recommendations about current paddling options.

The ratings from the RTRC were converted to numerical scores from 1 to 7 with the two ratings for 'river' and 'rapids' being averaged (equal weighting). A suitability score was thus provided with '4' representing 'optimal' flow (Fig. 3).

These raw data plots generally produced rather scattered distributions that did not indicate clear thresholds relative to flow suitability. The scattered data were difficult to interpret without statistical assessment and two statistical approaches were applied.

The focus of the current analyses was to determine low flow criteria and consequently analyses considered the lower portion of the response data. A regression method commenced by recognizing the range of flows that were considered by some respondents as lower than ideal. Flows that were consistently judged as 'just right' or higher were above this threshold and these were omitted from subsequent curve-fitting regression.

The remaining data were evaluated through linear and polynomial regression and the simplest function (lowest polynomial order) was selected that produced a near-maximal coefficient of determination (r^2). A curved response function was expected since it was anticipated that low flows would provide little improvement over the no-flow point up to the discharge at which the stream was approaching the depth that would consistently float a boat over riffles and permit full paddle blade immersion in most areas. Thereafter, it was expected that the suitability function would increase and then flatten out as the ideal flow range was approached.

Following the regression calculation, the intercepts of the line of best fit with suitability ratings of 3 and 3.5 were identified and the associated discharges were interpolated to reflect the minimum and sufficient flows.

The second statistical approach involved grouping ratings from particular flow ranges (Fig. 5). Groups consisted of 5 m^3/s intervals except for the small Crowsnest River, for which intervals consisted of 4 m^3/s. These grouped intervals provided the independent variable categories for analyses of variance (ANOVA). For all streams, the ANOVA's confirmed that suitability ratings varied significantly ($P<0.001$) across flow interval groups.

The flow group means were plotted and the groups with standard error ranges associated with the suitability ratings of 3 and 3.5 were recognized to represent minimum and sufficient flow groupings, respectively. The mid-group flows (i.e. 17.5 m^3/s for group '15', representing 15 to 20 m^3/s (Fig. 5)) were consequently selected as the relevant values.

The values from the two statistical approaches were very similar for each river reach and these two values were averaged to produce 'minimum' and 'sufficient' RTRC values that were used for further comparisons. The regression analysis provided a more refined analysis and is probably better suited to these data that involve continuous variation in discharge. The regression analysis is thus recommended for future analyses of similar survey data.

Figure 3. Plotted data for the River Trip Report Cards (RTRC) submitted for the Milk River. The best fit 2nd degree polynomial regression curve is plotted and the coefficient of determination (r^2) 0.32. RF minimal and sufficient flows were determined by interpolating the discharges associated with suitabilities of 3 and 3.5, respectively, from the regression curves. The 'optimal' flow is also indicated as the intercept associated with the suitability of 4.0. However, the present study does not focus on optimal flow determination and subsequent analyses consider only the minimal and sufficient flows.

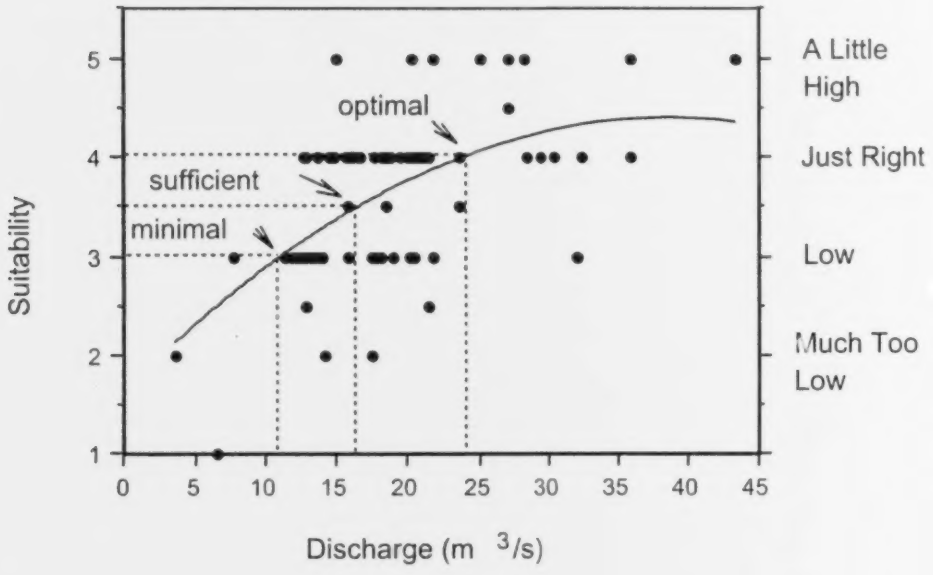


Figure 4 (next page). Plotted data for River Trip Report Cards (RTRC) submitted for the Crowsnest (top), Castle (middle) and Upper St. Mary (bottom) rivers, Alberta. Only the low discharge (flow) range is presented and additional RTRC had been submitted for higher discharges than plotted. The regression for the Castle was restricted to the range indicated by the line; data indicated by square symbols were not included since they reduced the regression fit in the range of interest. Coefficients of determination (r^2) were 0.66, 0.56 and 0.74, respectively. Dashed lines indicate the minimal and sufficient flows that correspond to suitabilities of 3 and 3.5, respectively. Note the different X-axis scales for the different plots.

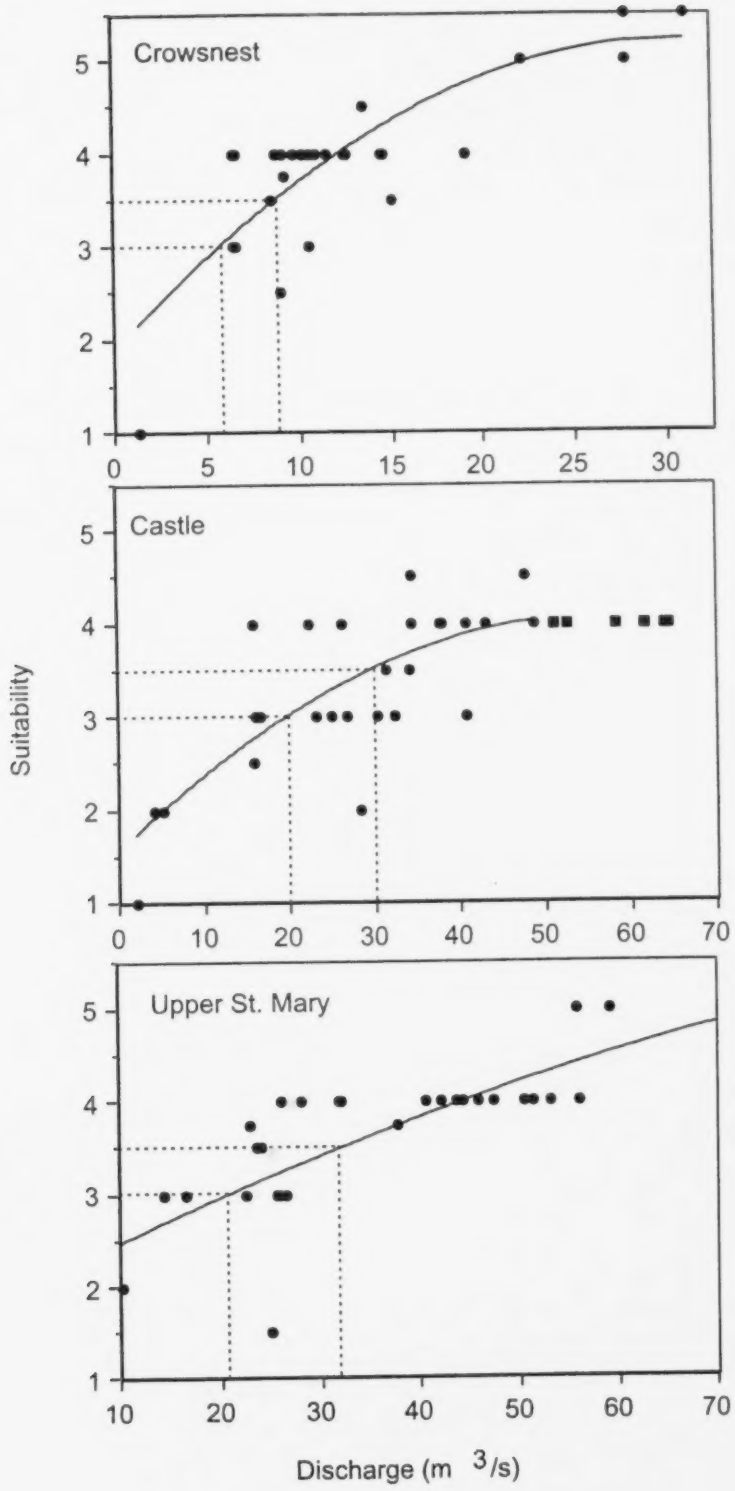
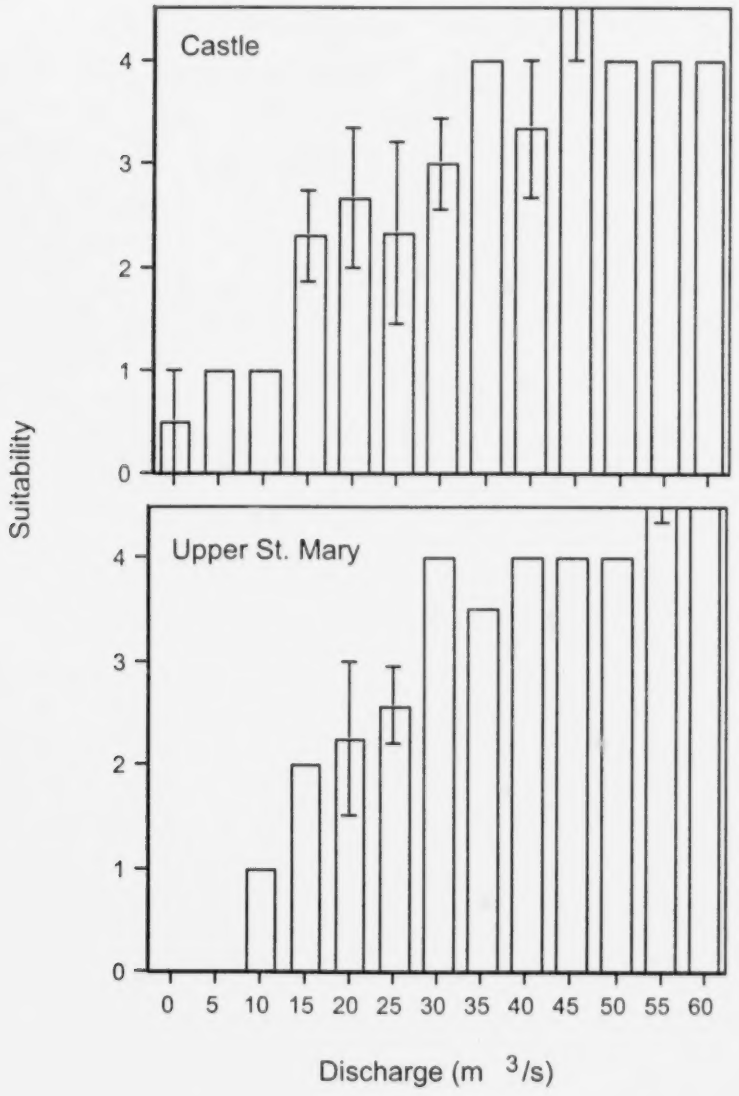

Crowsnest
Castle
Upper St. Mary
Suitability
Discharge (m 3/s)

Figure 5. Grouped River Trip Report Card (RTRC) data for the Castle (top) and Upper St. Mary rivers, Alberta. Discharge (flow) groupings of 5 m^3/s were established (for example, '0' represents 0 to 5 m^3/s) and suitability assessments were averaged $\pm$ s.e..



The RTRC paddler survey was voluntary and anonymous. However, about one-half of the respondents for the Oldman River Basin identified themselves and these known respondents tended to reflect two paddler types. One type involved individual paddlers who were generally recognized as prominent local paddlers that were interested in river resource management and often worked in the field of environmental science, outdoor recreation instruction and/or guiding and/or were involved in competitive paddling. Although comparisons are not fully developed there were no obvious inconsistencies between the suitability ratings from these experienced paddlers and ratings from the anonymous contributors.

The second group of known RTRC contributors involved paddling clubs and particularly members from the Lethbridge-centered ORCKA and the Bow Waters Canoe Club from Calgary. These groups tended to identify their club affiliation and the trips tended to involve large paddler groups. The club submissions were generally quite thorough with respect to completion of the RTRC and also included interesting and sometimes entertaining comments, sometimes referring to the RTRC program and the broader task of determining RF.

The club submissions also often provided views about the difficulty of the river reach as well as their assessments of RF for the reach. Thus, some individuals and clubs had conducted informal (or even deliberate) multiple flow comparison-type RF analyses.

The recognition that a few paddlers and paddler groups contributed many RTRC indicates that this paddler survey did not represent a random sample relative to the complete paddling community. Although minor in effort, the RTRC task might conflict with the view that the weekend or afternoon paddle is a recreational activity that should not involve 'work'. Thus, this type of report card submission probably generates a different participation profile than some other types of paddler surveys such as oral interviews conducted at take-out points.

The reaches assessed with RTRC for the Oldman Basin are summarized in Table 1. The Oldman River was generally well represented, as was the Castle River, a popular stream largely situated within the Provincial (public) lands of the Bow Crow Forest Reserve.

As expected, the lower reaches of the St. Mary and Waterton rivers were minimally represented and this probably reflects their limited use by recreational paddlers. However, this was probably not due to paddling appeal but instead was due to the severe flow diversions from these streams that resulted in insufficient flows for paddling through the summers of most years.

The limited use of the lower St. Mary River is especially noteworthy since this reach represents a particularly favorable paddling opportunity. The river has cut deeply incised meanders into sandstone

bedrock to create a distinctive landscape and an exceptional resource for recreational paddling. Bedrock features create sharp hydrologic features that are ideal for 'play' paddling, surfing and whitewater stunts that are increasingly sought after by recreational boaters. While the damming and diversion have restricted the paddling opportunity along the lower St. Mary River when it flows sufficiently, paddlers enjoy warm water that results from top release from the St. Mary Reservoir. This combination of warm water and whitewater is unique in Alberta.

Expert Opinion

For the RF approach involving exert opinion, the present study considered the various guidebooks and guide maps for rivers in southern Alberta. Six regional guides were identified and of these, three provided information that was considered reliable and applicable to RF determination.

The two guidebooks and the regional recreational map that were chosen included recommendations regarding paddleable flows. However, particularly in the guidebooks, the categorization of the flow recommendations varied across rivers and was sometimes incorporated into variable text that introduced additional ambiguity.

The flow recommendations were fairly consistent across the three guides. The later guides would have benefited from the earlier information and thus, the three recommendations are not independent. However, they are not duplicates either since both Smith (1995) and the SABDC (1998) guides provide some changes from the initial assessments by Buhrmann and Young (1982).

The different guides were written by paddlers that used different boat types and have different 'comfort zones', a description of the whitewater difficulty in which the paddlers are comfortably proficient. Buhrmann and Young (1982) used aluminum, tandem open canoes that are vulnerable to swamping (although Buhrmann and Young did use spray covers) and incapable of the Eskimo roll, the method for an unassisted instream recovery from a capsize. Smith (1995) is an expert, 'class V' kayaker who generally used durable, polyethylene whitewater kayaks that are not vulnerable to swamping and very maneuverable. The SABDC (1998) guide particularly included assessment from Chuck Lee, a versatile paddler who is an expert in open canoes as well as in closed canoes and kayaks. The differences in boat types and comfort levels probably influenced flow assessments and Buhrmann and Young (1982) generally provided higher whitewater difficulty ratings and lower suitable low flow recommendations than Smith (1995) or the SABDC (1998).

Multiple Flow Comparisons

The guidebooks rely on expert opinion that involved some knowledge and investigation of river sizes and historical hydrographs that complemented the authors' paddling experiences that often involved multiple trips along some reaches. Consequently, the guidebook assessments partly reflect a 'multiple flow comparison' style of subjective assessment of RF. The present study invoked an additional multiple flow comparison that was both more deliberate and more extensive than the paddling experiences of the guidebook authors on the river reaches of this study.

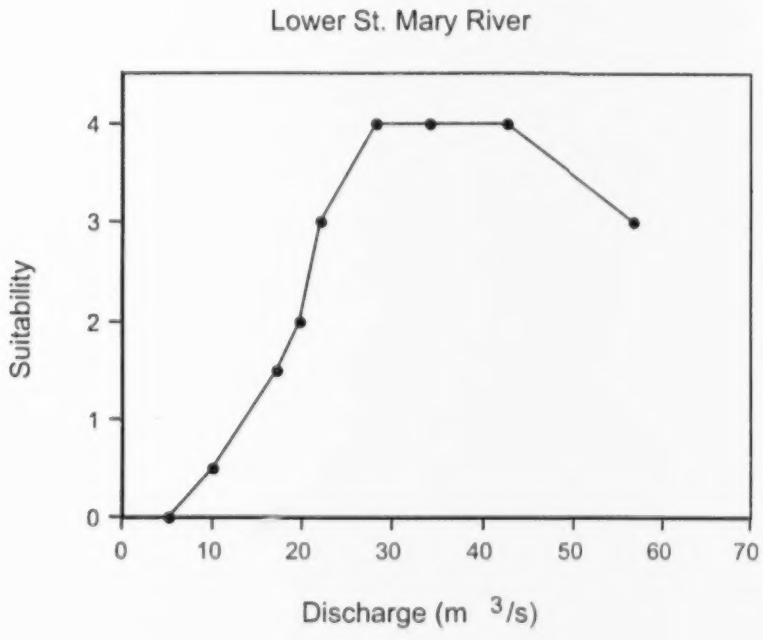
We visited all of the river reaches of the present study at various flows and paddled most reaches at least twenty times. The experience provided additional assessment and strengthened our confidence of the minimum and sufficient flow assessments. We also deliberately paddled in open canoes, kayaks and rafts and with different groups of paddlers who provided feedback about the experience of individuals from novice to expert skill levels.

Consistent with the functions described by other RF investigators (Shelby et al. 1992), the suitability versus discharge function was a skewed bell-curve with a broad apex (Fig. 6). Flows were insufficient for paddling up to the point where the boats would be floatable over the typical riffle sections. This would be the 'much too low' limit for paddling and above this discharge, the suitability improved rapidly.

The 'minimal' flow suitability value of 3 would provide a measure of paddleability that we considered to provide a reasonably favorable recreational experience. A relatively small increase in discharge brings the stream up to the 'sufficient' or 'preferred' flow and thereafter, the suitability function flattens out through the broad range of flows that are considered 'optimal'. There is no specific optimum and the flows would be ideal over a fairly broad range. Certain flow-related features are favored at particular flow ranges whereas other features improve with different flows.

Probably the most subjective aspect of the suitability function is the point at which flows become too high. There are substantial differences in the evaluation of flows that are 'slightly high' or 'high' since different paddlers have different preferences relative to flow velocity, wave abundance and size, hydraulic turbulence and other hydrologic factors. Additionally, most paddlers favor clear water but turbidity increases with flow and thus counters improvements due to increasing depth, velocity and turbulence. Higher flows also generally provide colder water conditions in southwestern Alberta, another generally undesirable correlate of increasing flows. The present study focused on the development of methods to define minimal and sufficient flows and the issues associated with determination of the upper ranges of the suitability curve were not stressed in the present analysis.

Figure 6. The results of the multiple flow comparison for recreational paddling along the Lower St. Mary River, Alberta. The river was visited at differing discharges (flows) and the paddling suitability was evaluated by the authors.



Hydrometric Analysis - the Depth, Discharge Method (DDM)

A number of previous researchers have applied various hydrometric methods for RF analysis. Whittaker et al. (1993) categorized these approaches as 'prediction-based modeling methods'. The prior methods by Tennant (1976) and Corbett (1990) sought simple quantitative relationships that would identify particular proportions of mean annual flow that would offer suitable conditions for recreational boating and other uses. Whittaker et al. (1993) conclude that these approaches offer useful estimates but have significant weaknesses and Burley (1990) provides additional reasons why simple RF methods may fail.

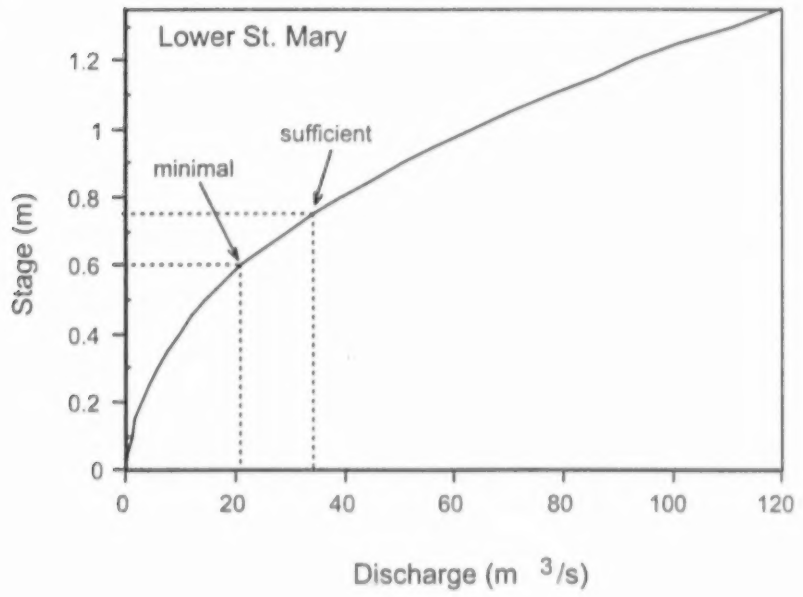
Although we fully agree that various complexities exist, our view is that river depth is the critical flow-related variable and thus, a depth-based hydrometric approach should be useful for RF investigation. While the 'single transect' and 'instream flow incremental' should thus offer promise for RF analysis (Whittaker et al. 1993), we had been developing hydrologic methods for RF analysis independent of the applications described by Whittaker et al. (1993) and in our applications, a relatively simple hydrologic approach showed considerable promise.

Like the single transect and instream flow incremental methods and design considerations for artificial canoe and kayak slalom sites (McGill 1972, Simmons et al. 1977), our depth, discharge method (DDM) considered that the low flow limitation for recreational boating would be insufficient depth for boat passage and paddle immersion. Most canoes and kayaks require depths of only 10 to 20 cm to float the boat. However, since there is variation in stream channel width and slope as well as common rock obstructions, the typical depth must be much deeper than 10 to 20 cm to provide this depth in the shallow areas. The single transect method relies on identifying the particular shallow location that will initially limit paddling and subsequently, the flow providing the sufficient 10 to 20 cm depth at that point is determined.

The single transect method requires considerable field work to identify the limiting location for paddling. Additionally, stream channels are particularly dynamic and thus flood events, ice jams, rock slides or other geomorphic factors will change the flow-limiting location over time. We thus consider that a general depth criterion is preferable to a single transect analysis. For the present study, the sites of hydrometric gauging stations were visited and were considered to be reasonably typical of the respective river reaches relative to overall channel geometry. Consequently stage-discharge ratings curves for these gauging sites were used in subsequent RF analyses (Fig. 7). We were cautious in this implementation since we anticipated substantial site-specific variation in stage-discharge pattern. The measurements along the Upper St. Mary River indicated three-fold differences in the stage change associated with discharge change from minimal to sufficient flows. These differences particularly reflect positions relative to rapids and bedrock confinement and there are also a number of other factors that would disturb the

simple depth discharge analysis. The appropriate test of this method is the comparison of its results with results from other RF approaches and this was a focus of the current study.

Figure 7. The stage versus discharge (flow) or 'ratings' curve for the site of the stream flow gauge along the Lower St. Mary River, Alberta. The depth, discharge method (DDM) is applied, whereby the discharge associated with depths (stages) of 60 cm (0.6 m) and 75 cm are interpolated to provide RF estimates for minimum and sufficient flows, respectively.



Comparisons across RF Methods

The different subjective appraisals were very consistent with respect to estimates of minimum in stream flows that are suitable for recreational paddling (Table 2). The Buhrmann and Young (1982) estimates were earliest and displayed less variation than the subsequent estimates by Smith (1995) and SABDC (1998). Two particular values from Buhrmann and Young (1982) were inconsistent with the other estimates; the estimate for the Upper Oldman was very low whereas the estimate for the Crowsnest River was high. More recent paddler assessments would have benefited from prior estimates and it is likely that minimum flow estimates would be progressively refined over time.

The River Trip Report Card determinations were also very consistent with the expert opinion assessments, as were the multiple flow comparison values. The average coefficient of determination (r^2) across the subjective assessments was 0.54 (n=10, P<0.001), confirming the high degree of correlation across methods. The Buhrmann and Young (1982) determinations were least consistent of the subjective methods and the average coefficient of determination (r^2) without these values as 0.63 (n=6, P<0.001). Mean subjective scores were calculated by averaging all of the subjective methods with no differential weighting. There may have been some merit in providing a heavier waiting for the later analyses but this would have had a minor influence on the outcomes since five values were averaged.

Table 2. Minimal flows for recreational paddling along ten southern Alberta river reaches as determined by various subjective methods. Legend: B & Y = Buhrmann and Young (1982), Smith (1995), SABDC = Southern Alberta Business Development Center (1998), RTRC = River trip report cards, MFC = multiple flow comparison.

	B & Y	Smith	SABDC	RTRC	MFC	Average
			(m^3/s)			
Upper Oldman	8	20	20	11	14	14.6
Lower Oldman	28			25	27	26.7
Crowsnest	11	7	8	7	6	7.8
Castle	16	20	22	20	15	18.6
Upper Waterton	14	22	15		16	16.8
Lower Waterton	14	30	25			23.0
Upper Belly	7	15	15	8		11.3
Upper St. Mary	14	15		21	16	16.5
Lower St. Mary	14	20		18	20	18.0
Milk	14			11		12.5
Average	14.0	18.6	17.5	15.1	16.3	16.6

The subjective method estimates for sufficient flows were also very consistent across different approaches (Table 3). For these values the multiple flow comparison consistently provided slightly lower flow estimates and this may have reflected our particular views about flow sufficiency. In any subjective approach there will always be variation in opinion across observers and it is consequently important to incorporate a range of viewpoints.

Table 3. 'Sufficient' or 'preferred' flows for recreational paddling along ten southern Alberta river reaches as determined by various subjective methods and by the depth, discharge method (DDM), using a depth criterion of 75 cm.

	B & Y	RTRC	MFC (m3/s)	Average Subjective	DDM	Subjective/ DDM
Upper Oldman	23	16	22	20	33	0.62
Lower Oldman	57	60	45	54	35	1.54
Crowsnest	20	9	9	13	12	1.06
Castle	23	30	25	26	23	1.13
Upper Waterton	42		26	34	32	1.06
Lower Waterton	42			42	50	0.84
Upper Belly	14	14		14	16	0.88
Upper St. Mary	34	32	30	32	28	1.14
Lower St. Mary	42	30	28	33	35	0.95
Milk	23	16		20	14	1.44
Average	32.0	25.9	26.4	28.1	27.8	1.07
Excluding Lower Oldman						1.01

A strength of the depth discharge method (DDM) is that it is based on specific physical parameters and avoids the imprecision of subjective valuation; however, this physical approach would only be useful if the output is consistent with subjective assessment that is the ultimate aim of the RF analysis. This was the case in the present study as the DDM estimates for both minimum and sufficient flows were consistently very close to the aggregate estimates based on the subjective methods. Some specific comparisons are plotted in Figure 8 and the values are fully listed in Table 4.

The full range of streams are represented in Figure 9 with the aggregate subjective method minima plotted against the DDM determination. There was very close correlation between the subjective and DDM method estimates and the overall coefficient of determination (r^2) was 0.66. The Lower Oldman reach represented the combined flow of all of the other reaches and was thus a much larger stream than the others. The DDM method underestimated the lower Oldman minimum relative to the estimate from the subjective methods and this data point was furthest from the regression fit for the collective data. Excluding this reach, the coefficient of determination (r^2) increased to 0.78; thus, 78% of the variation of the subjective method RF estimate was associated with variation in the DDM estimate. This confirms the

high degree of agreement across these subjective and hydrometric methods.

Earlier researchers had investigated the application of simple ratios between paddleable flows and broader hydrologic characteristics, particularly the mean annual discharge (Corbett 1990, Tennant 1976). We also investigated such relationships and were surprised at the very close correlation between mean annual discharge (Q) and the aggregate estimate of minimum flow for recreational paddling (Table 4). Again excluding the much larger lower Oldman River, there was very close agreement in the aggregate RF minimum and the mean annual discharge of the reach (Fig. 10). The coefficient of determination (r^2) was 0.90, reflecting an exceptionally close correlation across these values. Additionally, the data were positioned very close to the 1-to-1 line (unit slope, origin intercept) indicating that the mean discharge values could provide reasonable estimates of the RF minimum for these streams (Fig. 10).

Table 4. Minimal flows for recreational paddling along 10 southern Alberta river reaches, as determined by subjective methods (Table 2) and by the depth, discharge method (DDM), using a depth criterion of 60 cm, along with mean annual discharges and various ratios of these parameters.

	mean Subjective	DDM	mean Minimum	Subjective/ DDM	mean Q	mean Q/ mean Min.
Upper Oldman	14.6	21	17.8	0.70	13.1	0.74
Lower Oldman	26.7	22	24.3	1.21	83.7	3.44
Crowsnest	7.8	7	7.4	1.11	4.9	0.66
Castle	18.6	14	16.3	1.33	15.9	0.98
Upper Waterton	16.8	15	15.9	1.12	18.2	1.15
Lower Waterton	23.0	30	26.5	0.77	26.7	1.01
Upper Belly	11.3	9	10.1	1.25	8.7	0.8ᵬ
Upper St. Mary	16.5	17	16.8	0.97	20.7	1.24
Lower St. Mary	18.0	20	19.0	0.90	15.1	0.79
Milk	12.5	9	10.5	1.47	9.1	0.86
Average	16.6	16.4	16.5	1.1	21.6	1.17
Excluding Lower Oldman						0.92

Figure 8. Estimates of minimal (open bars) and sufficient (shaded bars) flows (discharges) for recreational paddling along four river reaches in Alberta. For each river, the bars represent values from: River Trip Report Cards (RTRC), paddling guides by Buhrmann and Young (1982) ('B & Y'), Smith (1995), the multiple flow comparison, and the depth, discharge method (DDM).

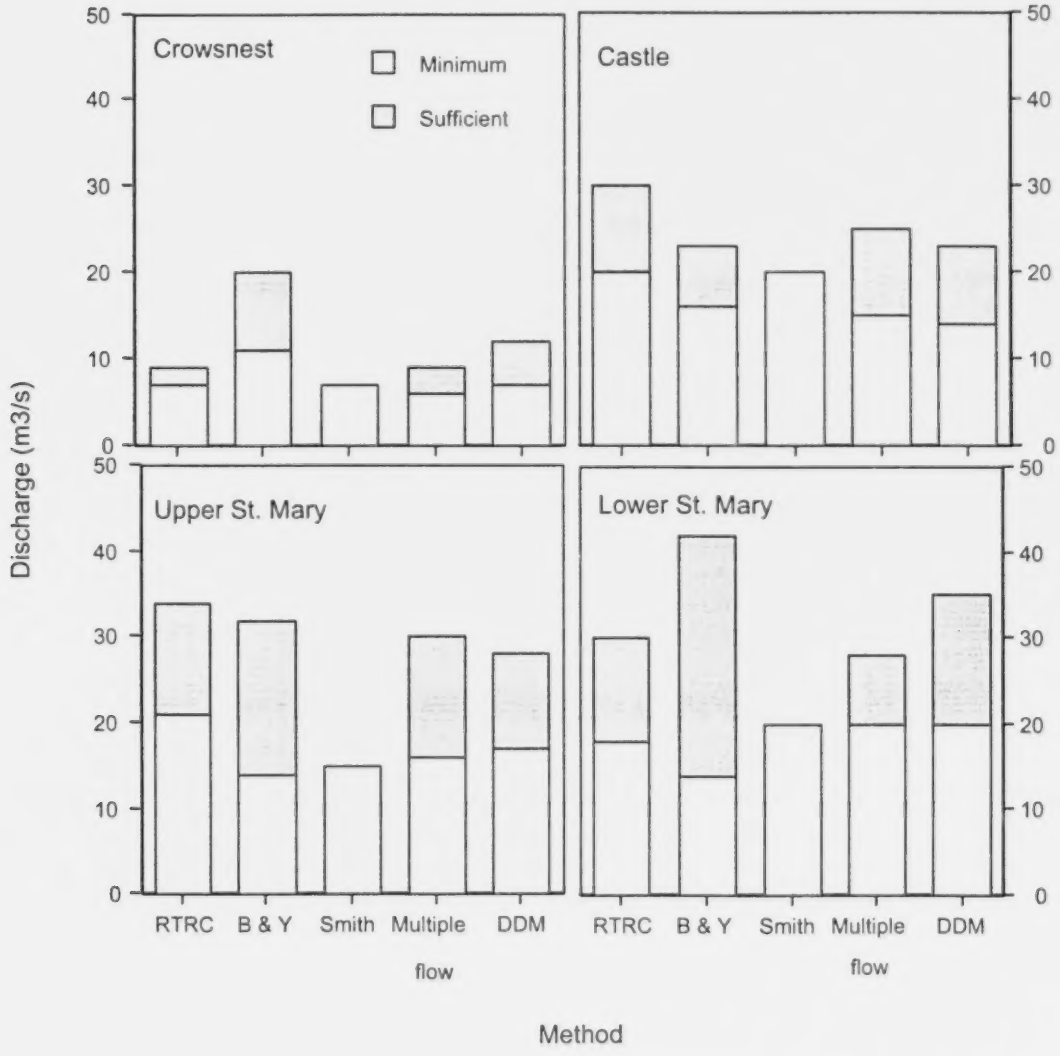


Figure 9. Average minimal flows for recreation as determined from the various subjective methods of the present study (Table 3) versus the minimum flow as determined by the depth, discharge method (DDM). The dashed line has a unit (1) slope and origin (0,0) intercept. The solid line represents the best-fit linear regression of the data excluding the Lower Oldman ($y = 0.52x + 7.6$; $r^2 = 0.779$). The best fit including the Lower Oldman was $y = 0.62x + 6.8$; $r^2 = 0.658$).

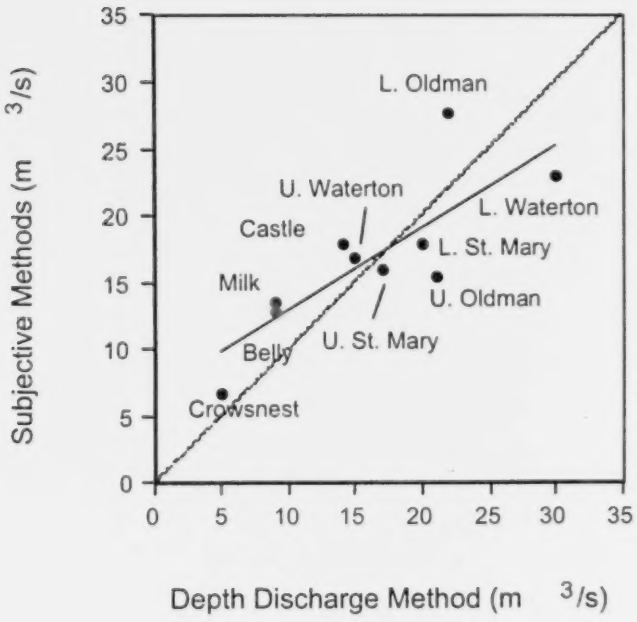
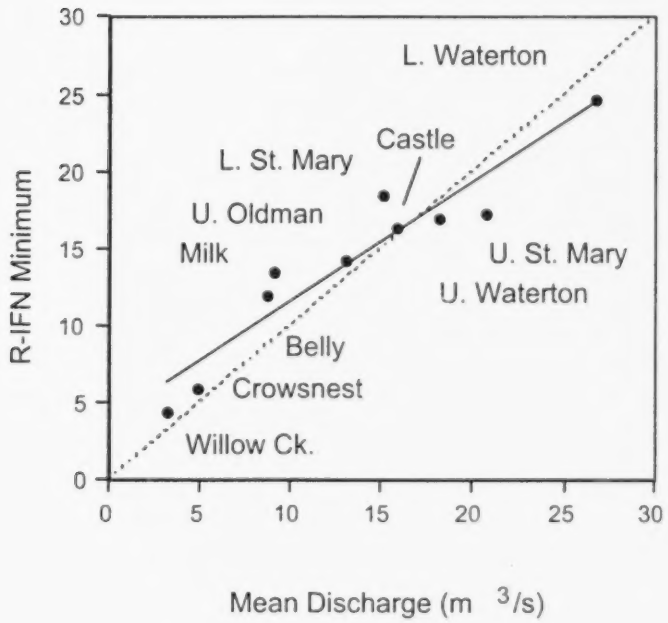


Figure 10. Average minimal flows for recreation (mean of all methods, Table 3) versus the mean annual discharge (Q) for rivers in the Oldman River Basin, Alberta, excluding the large Lower Oldman River but including Willow Creek. The dashed line has a unit (1) slope and origin (0,0) intercept. The solid line represents the best-fit linear regression: y = 0.77x + 3.97.



This final relationship probably results from fundamental proportionalities between stream flow and channel geometry. The size of the stream channel is a particular physical consequence of stream flow and associated with this size, typical depth characteristics will result. It is thus reasonable that basic relationships exist between typical depth and flow. This simple relationship between RF minimum and mean discharge was expressed across a range of streams although these drained adjacent watersheds and all tended to be relatively small to medium in size. We expect that the relationship will not hold for larger streams but sufficient depth is less commonly a limitation for paddling in large rivers. It will be interesting to investigate the applicability of this simple relationship to other watersheds. We might expect the relationship to be similar across streams with similar physical environments. For example, this relationship might be broadly applicable across the foothills and western prairie streams that drain the east slope of the North American Rocky Mountains. The simplicity of the relationship warrants further investigation.

CONCLUSIONS AND RECOMMENDATIONS

The present study demonstrated very close agreement in estimates of RF from different methods for most rivers in the Oldman River Basin of Southern Alberta. Different subjective approaches generated very similar values that were also consistent with estimates based on a physical hydrometric method involving a combination of depth criteria and stage-discharge analysis. This strong agreement supports the validity of all of these methods. Further, the consistency across methods strengthens the confidence in the values that were determined. The final close relationship between mean annual discharge and minimum flow for recreational boating was unexpected and also provides another objective physical estimate that may be useful.

Following from the present study we recommend the application of the depth discharge method as an initial approach for RF minimum flow determination. The method is objective, quick and inexpensive, requiring only the hydrometric ratings curve for relevant stream gauge sites and visits to those sites to ensure appropriate channel geometry. We suggest that this DDM could be conducted at the onset of RF studies and this would provide initial estimates that would be the refined by subjective approaches involving paddler assessments. The initial DDM estimation should reduce the range of subjective assessments that would be required since this will provide an initial flow range for which subjective assessments would be focused. We do not recommend that any RF determination be solely based on physical hydrometric analyses since there is great diversity across streams that will influence the paddling experience. Since the ultimate objective is the determination of paddleable flows, paddler assessments must be included in RF studies. Further, we recommend that multiple approaches be applied. This would strengthen the analysis, broaden the range of opinions and also broaden the range of applications.

The depth discharge method also provides an opportunity for assessment of other instream recreation. Different depth criteria would be imposed for activities such as wading, tubing, swimming and jet boating and the DDM will again provide initial estimates for further refinement based on subjective assessment. We thus consider that the DDM could have broad usefulness in RF determination.

Acknowledgments

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Willow Creek

The Willow Creek drains foothills regions between the Upper Oldman and Highwood watersheds and has been dammed to provide water storage in Chain lakes and more recently, the Pine Coulee Reservoir. Although naturally characterized by a limited paddling season, Willow Creek provides a scenic paddling resource that includes a range of paddling opportunities including swift whitewater sections through bedrock canyons and slower flowing reaches where the stream meanders through cottonwood forests.

During the Pine Coulee project, the Wood Bay Consulting Group Ltd. (1996) evaluated RF of Willow Creek with reference to minimal flows for paddling and other instream recreational activities. However, that study determined RF minima of about 16 m^3/s for 4 of the 5 segments of Willow Creek. These are about three-fold higher than the flow recommendation of Buhrmann and Young (1982).

Wood Bay (1996) conducted a hydrometric analysis that incorporated both depth and width criteria along with velocity considerations. This approach was described as an instream flow incremental method (IFIM) approach although the IFIM more commonly applies particular depth or velocity criteria and then models the stream channel to determine two-dimensional areas that satisfy these criteria and hence, offers a quantitative analysis of different flow scenarios.

The depth criterion applied by Wood Bay (1996) was 75 cm and was thus consistent with our depth discharge method. However, Wood Bay (1996) also applied a width criterion of 8 m and we consider that this has inappropriately produced the high values for the RF minimum. The combination of a 75 cm depth over a full 8 m width is far more than is required for passage of canoes and kayaks.

Using our methodology as described in the prior section, the depth discharge method suggests that a discharge of about 5 m^3/s would provide a RF minimal flow and this value is slightly below the overall mean discharge of the stream (mean Q). This value is consistent with Buhrmann and Young's (1982) minimum of 5 m^3/s and those authors also suggest that the preferred flow would be about 11 m^3/s.

River Trip Report Card (RTRC) submissions are limited for the Willow Creek and indeed, we submitted one-half of the RTRC. These limited subjective evaluations report the flow as 'just right' at 10 m^3/s but low at 6 m^3/s and much too low at 2 m^3/s. Although limited in quantity and flow range, the RTRC submissions do support our other values. Thus, based on the report by Buhrmann and Young (1982), the depth discharge method analysis, our experience and the limited RTRC submissions, the minimal and preferred RF flows for Willow Creek would be about 6 and 10 m^3/s, respectively.

South Saskatchewan River

The South Saskatchewan River is formed by the junction of the Oldman and Bow rivers, near Grassy Lake, Alberta. This river generally flows through a relatively narrow valley that is flanked by steep coulees and cliff banks. With a very limited flood plain, meandering is also limited and in contrast to much of Oldman River upstream, the confined South Saskatchewan River valley supports only sparse bands of prairie cottonwood.

The longitudinal gradient of the South Saskatchewan River is very shallow and this gradual channel gradient produces fairly slow river velocities. Consequently, slow flow rather than insufficient channel depth is the principal flow-related impediment to recreational paddling. Due to these characteristics, the depth discharge method is inappropriate for the determination of RF for the South Saskatchewan River.

Due to remote location, limited access and the presence of the Suffield Canadian Forces Base, recreational use of the South Saskatchewan River has been rather limited. The exception involves the reach through the City of Medicine Hat that receives substantially more recreational use.

Reflecting the historically sparse use of the South Saskatchewan River as a recreational paddling resource, only eleven River Trip Report Cards (RTRC) were submitted for this Alberta river. Flows of 34 and 81 m^3/s were considered as much too low while flows of 145 and 549 were considered low (the latter report is peculiar). Flows of 107, 341, 576, 713, 857 and 1115 m^3/s were considered as 'just right' and a flow of 291 m^3/s was considered a 'little high'.

These values are generally consistent with the estimate of 55 m^3/s by Buhrmann and Young (1982) as the minimal flow. However, Buhrmann and Young (1982) did not visit the river below 150 m^3/s and their lower estimate is therefore somewhat speculative.

The South Saskatchewan River EcoCanoe Guide (SSREG) Companion Book describes the Saskatchewan reach of the South Saskatchewan River downstream from Gardiner Dam and through Saskatoon. That reach is downstream from the inflow of the Red Deer River, slightly downstream from the Alberta-Saskatchewan border and is somewhat less confined than the Alberta reach of the South Saskatchewan River. The SSREG suggests that 75 m^3/s might provide a lower end of paddleability and also discourages paddling above 1000 m^3/s.

Although somewhat provisional due to the limited data, these separate lines of evidence are reasonably consistent and collectively indicate that a flow of 60 m^3/s would be minimal and a flow of 100 m^3/s would be preferred (or 'sufficient') for the Alberta reach of the South Saskatchewan River.

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